Chapter 1 INTRODUCTION

Remote sensing is a technique for acquiring information, or intelligence, about areas of interest from some distance. As such, this is an important element of modern warfare. In this chapter, some of the basic motivating factors for the understanding of remote sensing will be developed. A brief introduction to some typical remote sensing products will be given, as well, in order to provide perspective for subsequent chapters.

A Order of Battle

The material in these notes is organized according to an ongoing usage of the paradigm provided by "Order of Battle", or OOB. This is largely associated with the counting of "things", but not entirely. Indeed, one thing for which care must be taken - don't limit the levels of information to simple 'counting'. We also need to pay attention to non-literal forms of information. Still, a large fraction of what we want to accomplish can be done by using this structure. Order of Battle has a number of forms, such as Ground Order of Battle (GOB), Air Order of Battle (AOB), etc. Some of the things one might like to know are enumerated according to this pattern:

1) Ground Order of Battle (GOB) - including logistics
2) Air Order of Battle (AOB)
3) Electronic Order of Battle (EOB)
4) Naval Order of Battle (NOB)
5) Industrial Order of Battle (IOB)
6) Cyber Order of Battle (COB)
7) Space Order of Battle (SOB)

What items characterize these OOB types? Taking GOB as an example, one might like to know about:

- Vehicles – numbers, locations, types…
  - e.g. armor (tanks) – operational status (fueled, hot, armed), capabilities, etc.
- Troops – numbers, arrangement, types…
- Defenses – mine fields, geography, missiles, chem/bio, camo, decoys…
- Infrastructure – roads, bridges…

Other examples follow.

1 Air Order of Battle

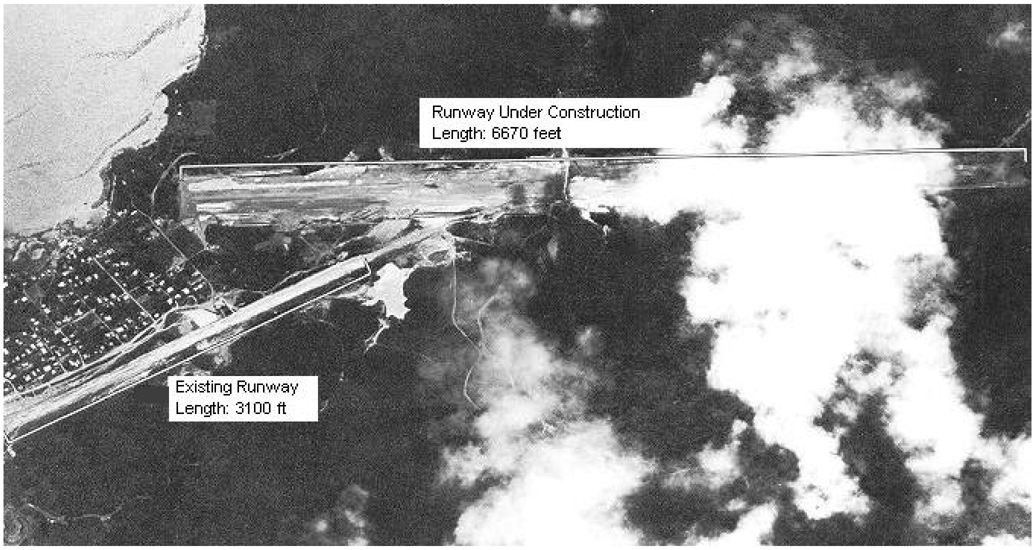

Figure 1-1. SR-71 image, Bluefields, Nicarauga, New runway under construction, 2 January 1982. http://www.fas.org/irp/imint/nic_13.htm

For AOB, you might want to know about:

- Planes – numbers, kinds, versions, unit IDs, operational status, armament, pilots, locations…
- Airfields – runway length, composition (material- asphalt, dirt, concrete), capacity, locations, bunkers, fuel (capacity, how full)

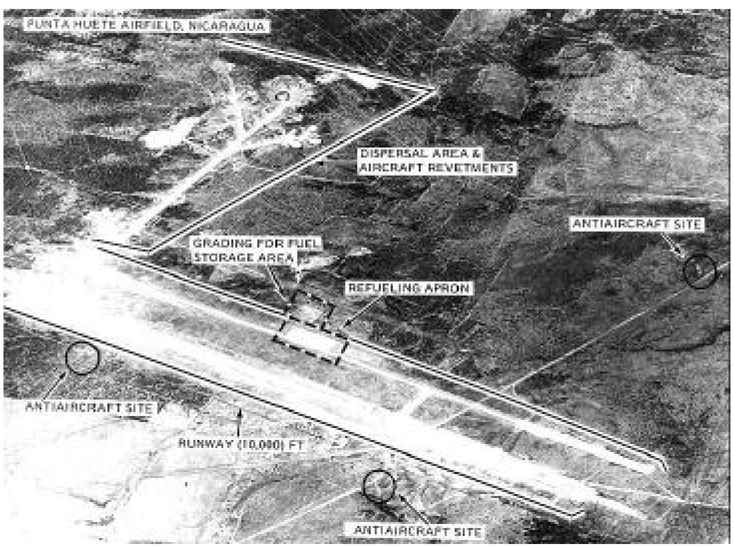

Figure 1-2. SR-71 image, Punta Huete Airfield, Nicarauga.
http://www.fas.org/irp/imint/nic_16.htm

Expanding on the general topics noted above, an ever more detailed list can be developed, as shown in the table here.

Air Order of Battle				
Planes	Type	Fighter	Weapons	Air-to-Air
				Air-to-Ground
			Sensors	FLIR
				Radar
				Visible
				EW
		Bomber		
		Tanker		
		Transport	Civilian	
			Military	
		Trainer		
		EW		
		Reconnaissance		
	Number			
	Locations	Bunkers		
		Runway		
		Aprons		
Runways	Length			
	Composition	(material- asphalt, dirt, concrete)		
	Direction			
	Approach	Terrain		
		Lighting		
		Weather		
		Ground Controllers		
Logistics	Supply Lines/ Lines of Communication			
POL	Fuel Tanks	Capacity		
		Type of Fuel		
		Fill Factor		
Pilots	Number			
	Ranks			
	Training			
	Experience			
Defenses	Weapons	AA guns		
		AA Missiles		
	Radar	Frequency		
		Range		
		Location		
		Type		
	Locations	FOV		

2 Electronic Order of Battle

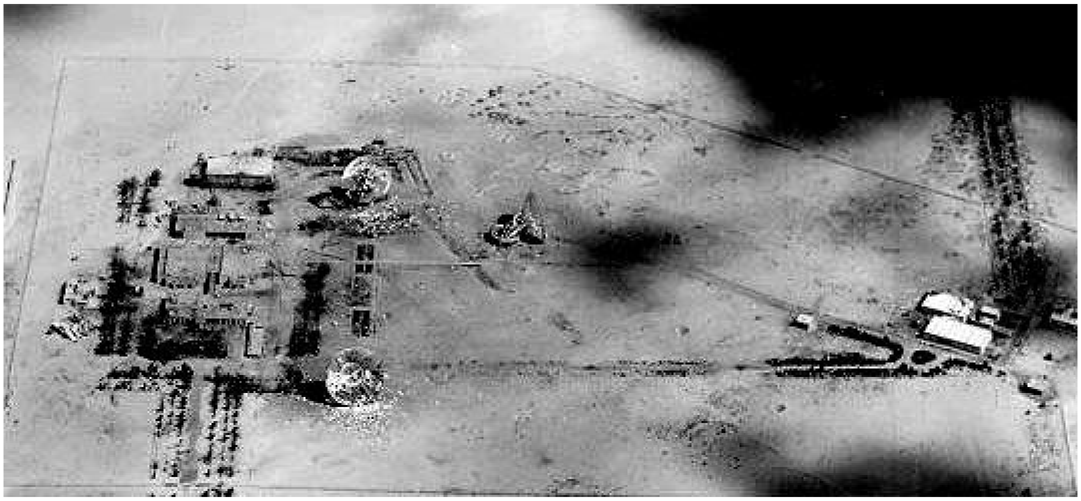

Figure 1-3. TARPS, (Tactical Airborne Reconnaissance Pod System) Umm al Aysh SATCOM, Federation of American Scientists Image, http://www.fas.org/irp/imint/alaysh.htm

- Defenses – SAM, radars…
  - Radars (technical details, and admittedly more SIGINT than IMINT) – frequencies, PRF, scan type, pulse width, mode-changing…
  - Radars – locations, ranges, operational patterns, networked?, EW requirements…
  - Radar Types - Air search, Surface search, Fire control, Target trackers.
- Communications – nodes, types (HF, µwave, fiber, etc.), commercial vs. military, encryption, interception and denial…
- Power – dams, power grid…

Figure 1-4. KH4 Corona image - Sary Shagan Operational Hen House Radar, http://www.fas.org/irp/imint/4_hen5.htm

3 Space Order of Battle

For SOB, you might want to know about two classes of things:

1) On the ground: launchers (boosters), pad or infrastructure, communications ground sites, and payloads
2) In space: communications (relays), payloads, orbital elements, constellations

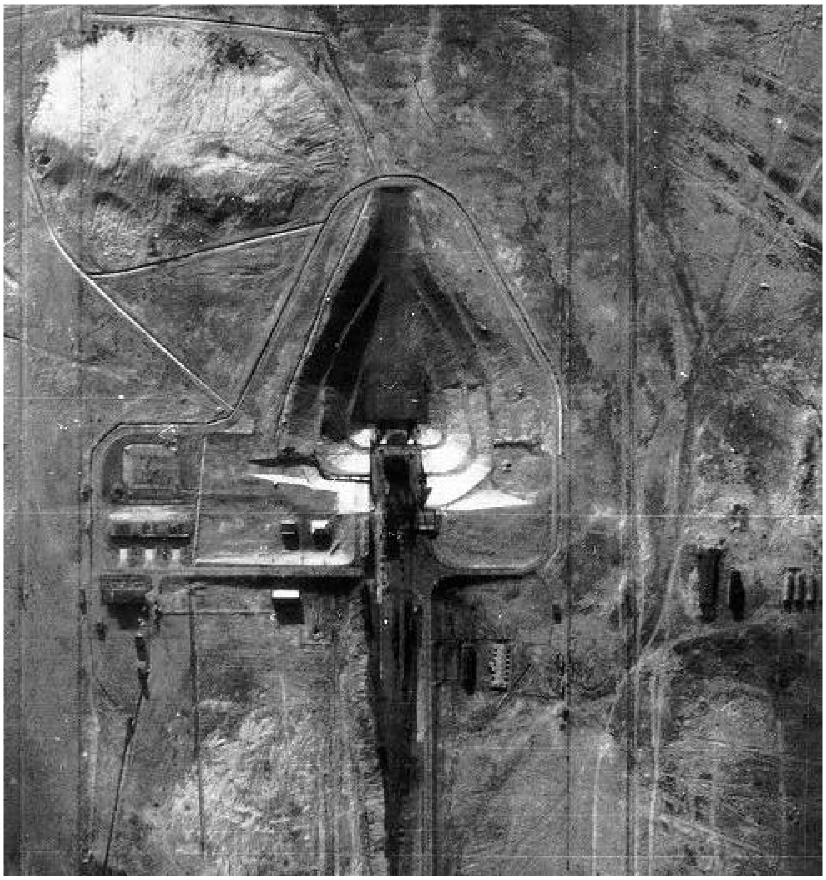

Figure 1-5. U2 image of SS-6 / Sputnik Launch Pad, Baikonur
http://www.fas.org/irp/imint/u-2_tt.htm

4 Naval Order of Battle

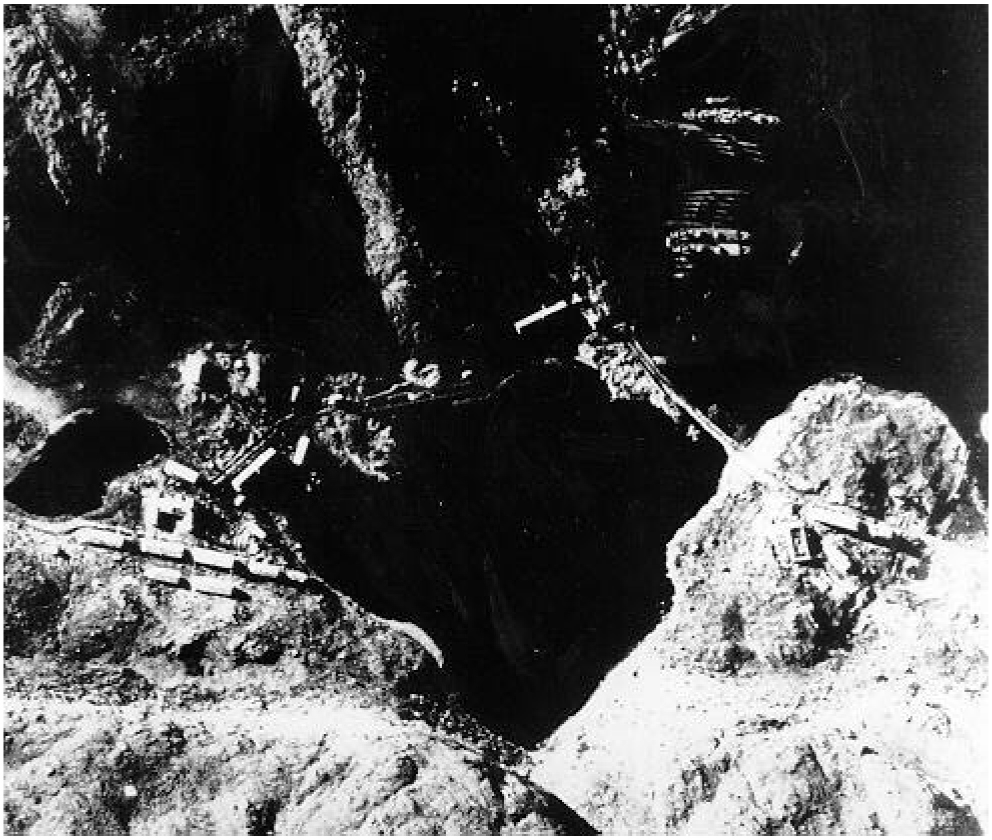

Figure 1-6. U-2 image of Soviet submarine pens,
http://www.fas.org/irp/imint/u-2_sub.htm
Sayda Guba, or Olenya Guba?

B Happy Snaps

In order to begin our study, we take an introductory look at images (often historical), which illustrate the range of data types found in the remote sensing community, and indicate how what we learn from remote sensing varies with spatial resolution and wavelength. We begin with whole earth visible imagery. The cover plate image from Apollo 17 is an early illustration. In sequence, below, we progress from resolution of 1 km to better than 1 meter. Following this will be a look at infrared and radar.

1 Visible

a GOES - whole earth

GOES 9 - visible image, 9 June 1995, 1815 UTC. The GOES 9 visible imager acquires an image once every 15 minutes at a spatial resolution of 1 km. The familiar nightly weather news will frequently be illustrated by images from one of the GOES satellites.

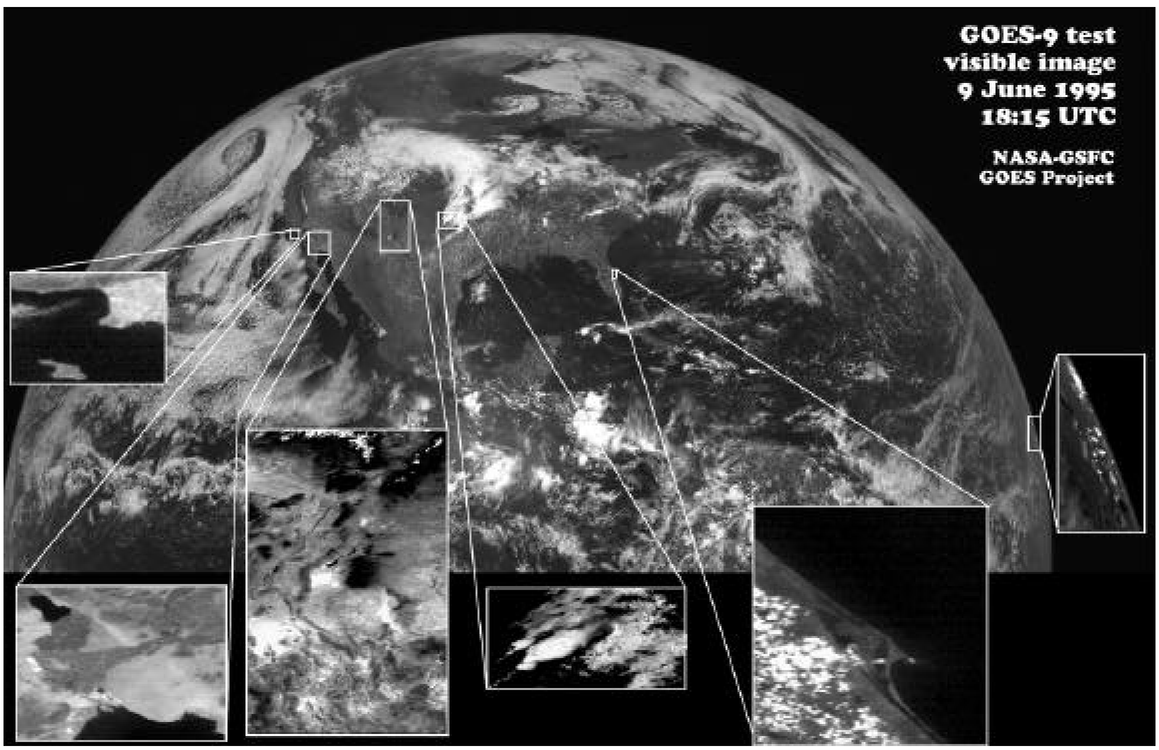

Figure 1-7 GOES-9 visible image, 9 June 1995, 18:15 UTC.

What value do such data have for the military? Clouds are a major element in modern warfare, directly affecting the ability of pilots and autonomous weapons to locate their targets. From the perspective of the sequence of images that begin here, this image also illustrates the beginning of an important set of trades between spatial resolution, frequency of coverage, and area of coverage. High altitude satellites, such as the geosynchronous weather satellites, provide large area coverage, more or less continuously. As noted above, the scanners produce an image every 15-30 minutes, at a spatial resolution of 1 km.

b DMSP (0.5 km), Earth at Night Landsat 5

A military variant on the more commonly seen weather satellites is given by DMSP. A low light capability gives DMSP the additional ability to see city lights, large fires (oil wells, forest fires), and the northern lights (aurora borealis). Such images provide some less-obvious value - for example, as indications of industrial capability. The image here is at a spatial resolution of 2.6 km. The imager is designed to see clouds at night (via moonshine), and the city lights saturate the photo-multiplier tube detectors (photon counters).

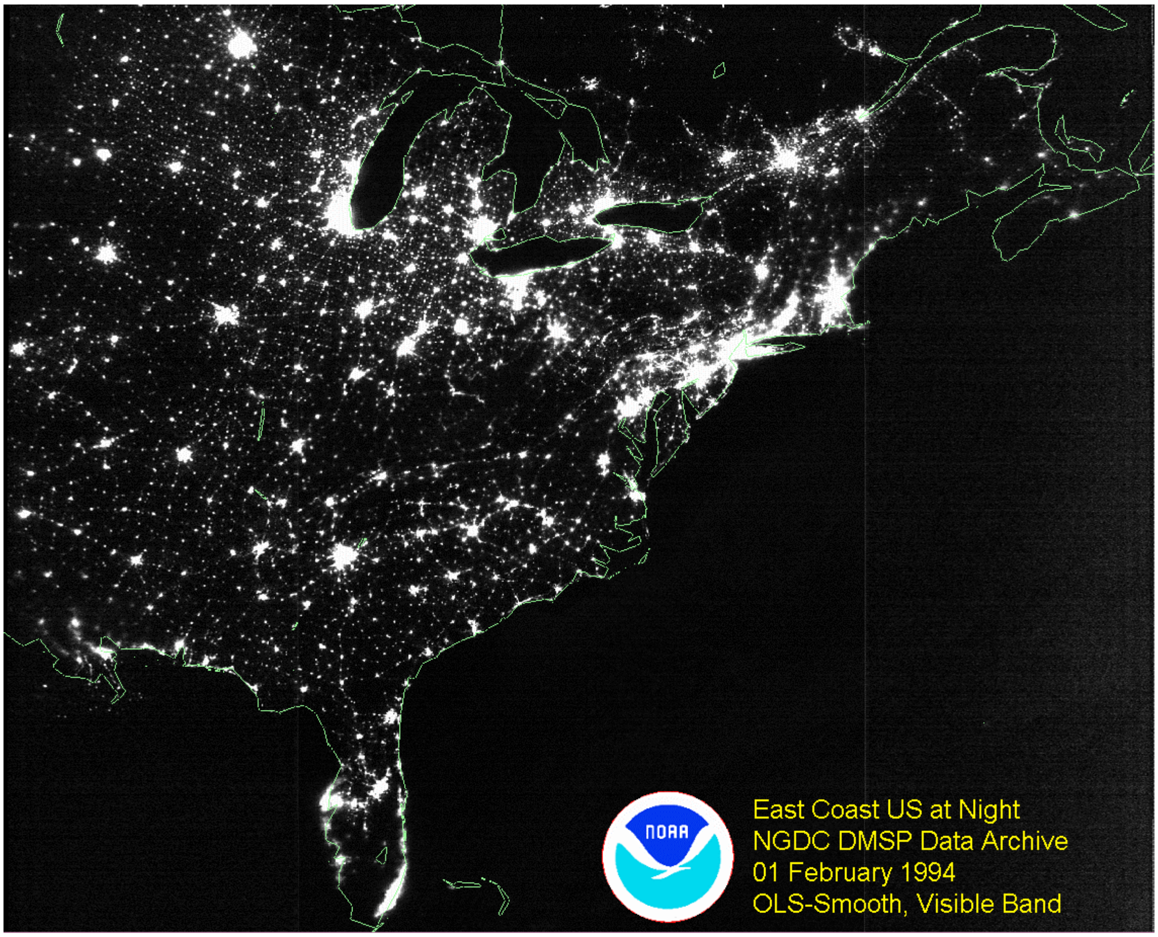

Figure 1-8. DMSP image of the East Coast at night.

By contrast with GOES, the DMSP imager only visits a given geographic region a few times a day. Orbiting at an altitude of 800 km or so, the daylight visible imager can take data at 1 km resolution. It provides coverage at high latitudes which cannot be obtained from the geosynchronous systems.

c UoSAT (100m)- San Francisco 18:59:15 29 August 1998

As the spatial resolution is increased, different sorts of features become more obvious. This image was taken by TMSAT, owned and operated by the Thai Microsatellite Company (TMSC), Bangkok, Thailand. TMSAT was designed and built by Surrey Satellite Technology Limited (SSTL) (http://www.sstl.co.uk/) a spin off from the University of Surrey, and the Surrey Space Centre. (http://www.ee.surrey.ac.uk/)

The TMSat microsatellite captured the image shown here on 29 August 1998 at 18:54:15 UTC (38.3°N 122.6°W) when over the cities of Oakland and San Francisco in California. This multispectral image was produced by combining the data from the three Narrow Angle Cameras, sensing in the green, red and near-IR spectra. Each image has 1020 x 1020 pixels, covering an area of 100 x 100 km at a mean ground resolution of 98 meters/pixel.

This imagery is a remarkable testimony to the possibilities inherent in small satellites.

Figure 1-9. TMSat image of San Francisco Bay.

Various man-made features are discernable. The Bay Bridge connecting San Francisco and Oakland is visible, but the Golden Gate Bridge is shrouded in sea mist. The runways at San Francisco and Oakland Airports stand out as long straight lines on the shores of the Bay. The variety of wavelengths gives additional information.

Red areas indicate healthy vegetation (due to the strong near-IR reflectance of chlorophyll), mainly forests on the Santa Cruz and Diablo mountains. Urban areas are generally blue-gray. To the right of the image, the intense agriculture of the Sacramento and San Joaquin valley is visible in the patchwork of fields. The different colors of these fields provides an indication of the state of vegetation (bare soil, marsh, young or mature vegetation, etc).

d Landsat 5 (30m)- San Diego - 7 May 1996 full scene and subset at full resolution

Multiple wavelength images (or multi-spectral) are most commonly applied to earth resources. Landsat provides higher spatial and spectral resolution than the previous example. Landsat has been the premiere earth resources satellite for two decades, providing 30-meter resolution imagery in 7 spectral bands. Imagery shown here has been taken from the three visible wavelength sensors, and combined to make a 'true' color image. The top frame is one complete Landsat scene. A small segment showing San Diego harbor has been extracted to illustrate the highest resolution of the TM sensor.

Figure 1-10 a

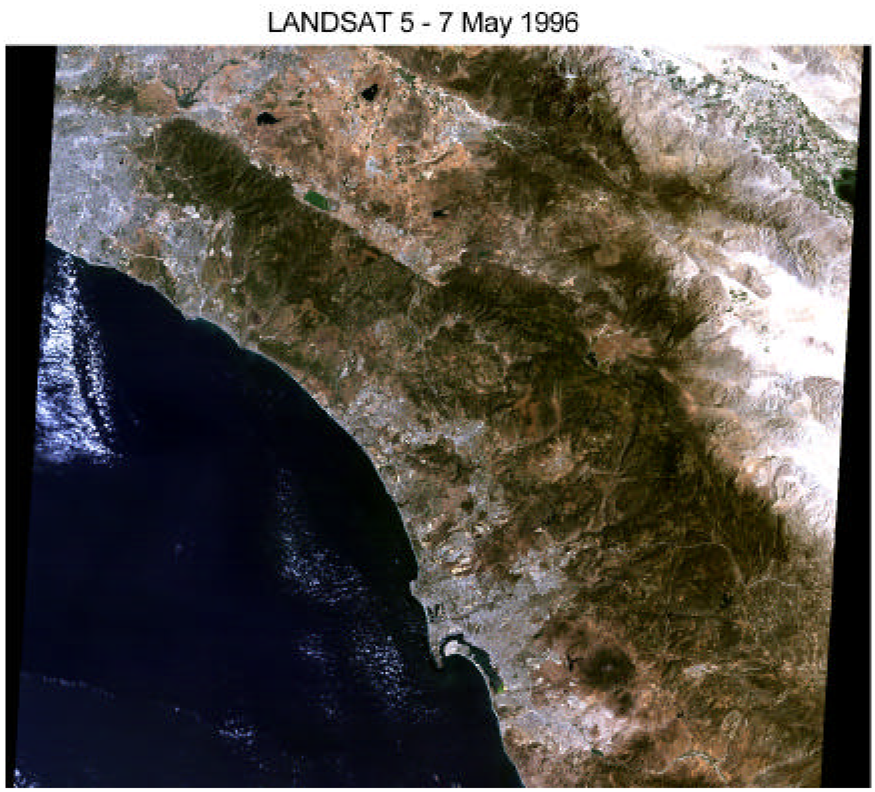

Figure 1-10 b

The penalty paid for this high spatial resolution is a relatively reduced field of view – nominally 100 km across in any given image. The low-altitude, polar orbiting satellite revisits each such region only once every 16 days.

e Shuttle 'handheld'

Just for comparison, the handheld Hasselblad camera on the space shuttle has produced a variety of noteworthy images over the years, such as this image of Egypt and Saudi Arabia. Spatial resolution is comparable to that of Landsat.

Figure 1-11. Eastern Egypt, the Red Sea, and Saudi Arabia, 4/29/90
NASA Photo ID: STS031-79-01, Film Type: 70mm.

Eastern Egypt, the Red Sea and Saudi Arabia can all be seen in this single view of the Near East (26.5N, 36.5E) from 330 nautical mile orbit. Easily seen from this vantage point is eastern Egypt, the Nile River, Lake Nassar, the Red Sea and almost half of Saudi Arabia.

http://images.jsc.nasa.gov/images/pao/STS31/10063614.htm

Resolution varies with the lenses used. The 'standard' telephoto, a 250 mm optic, gives resolution similar to that of Landsat, as illustrated on the left below.

Figure 1-12. a) STS064-080-021 (STS064 launch September 9, 1994),

b) Landsat (subset of image shown in Figure 1-10)

f Spot (10 m)

For many years, the highest resolution commercial imagery available was from the French SPOT satellite. Featuring resolution with 10-meter resolution, SPOT data have often been combined with LANDSAT data in order to provide a sharper image. Here an image of San Diego County is shown to illustrate a full frame of data, and a chip is shown of the harbor area and downtown San Diego.

Figure 1-13a.

Figure 1-13b. San Diego Harbor, SPOT image.

Notice the implicit conflict that emerges here between coverage and spatial resolution, along with the total data volume associated with the image. Higher spatial resolution implies more pixels, and hence more bits.

g IRS - 5 meter resolution

The Indian Remote Sensing Satellite, IRS-1C, launched in December 1995, has provided some of the highest resolution unclassified images to date. The inset to figure 1-8 is the entire 'scene' - note the substantially reduced area of coverage compared to a Landsat scene as shown in figure 1-10a.

Figure 1-14. San Diego Harbor, IRS image.

Relate these scenes of San Diego Harbor to AOB and NOB. What can you see (and not see) at 5-10 meter resolution? Can you see ships at the piers? If you can, do you need to resolve them to identify them? What can you tell about San Diego airport? Coronado Naval Air Station? Lines of Communication?

h IKONOS - San Diego/Coronado Island

The recent launch of the IKONOS satellite has dramatically changed the stakes in the resolution fight. IKONOS offers 1-meter spatial resolution panchromatic imagery, and 4-meter resolution multi-spectral (color) imagery. Shown here is a color image of San Diego, California, taken on November 17, 1999.

Figure 1-15. Coronado Island, San Diego, California. Space Imaging, Inc.

i High resolution airborne - F-16, Recon-Optical

Still higher resolution is possible, primarily from airborne platforms. In the last few years, electronic cameras have been able to provide high resolution imagery, which historically was the domain of film.

Figure 1-16. Recon-optical air photo

2 Infrared (IR)

Infrared imagery offers several differences with respect to visible imager. Two big ones:
a) Thermal IR works at night, and
b) Mid-wave infrared (MWIR) and Long-wave infrared (LWIR) data allow for non-literal information - meaning temperature, and associated interesting things like thermal inertia.

a GOES 9 - whole earth, 11 July 1995, 1800 UTC

Wavelength bands: 3.9, 11, and 12 microns encoded as red, green blue. Note that per the usual convention with the weather satellites, the 'gray' scales have been inverted - colder is brighter, dark is hotter. This is so the cold clouds will appear white.

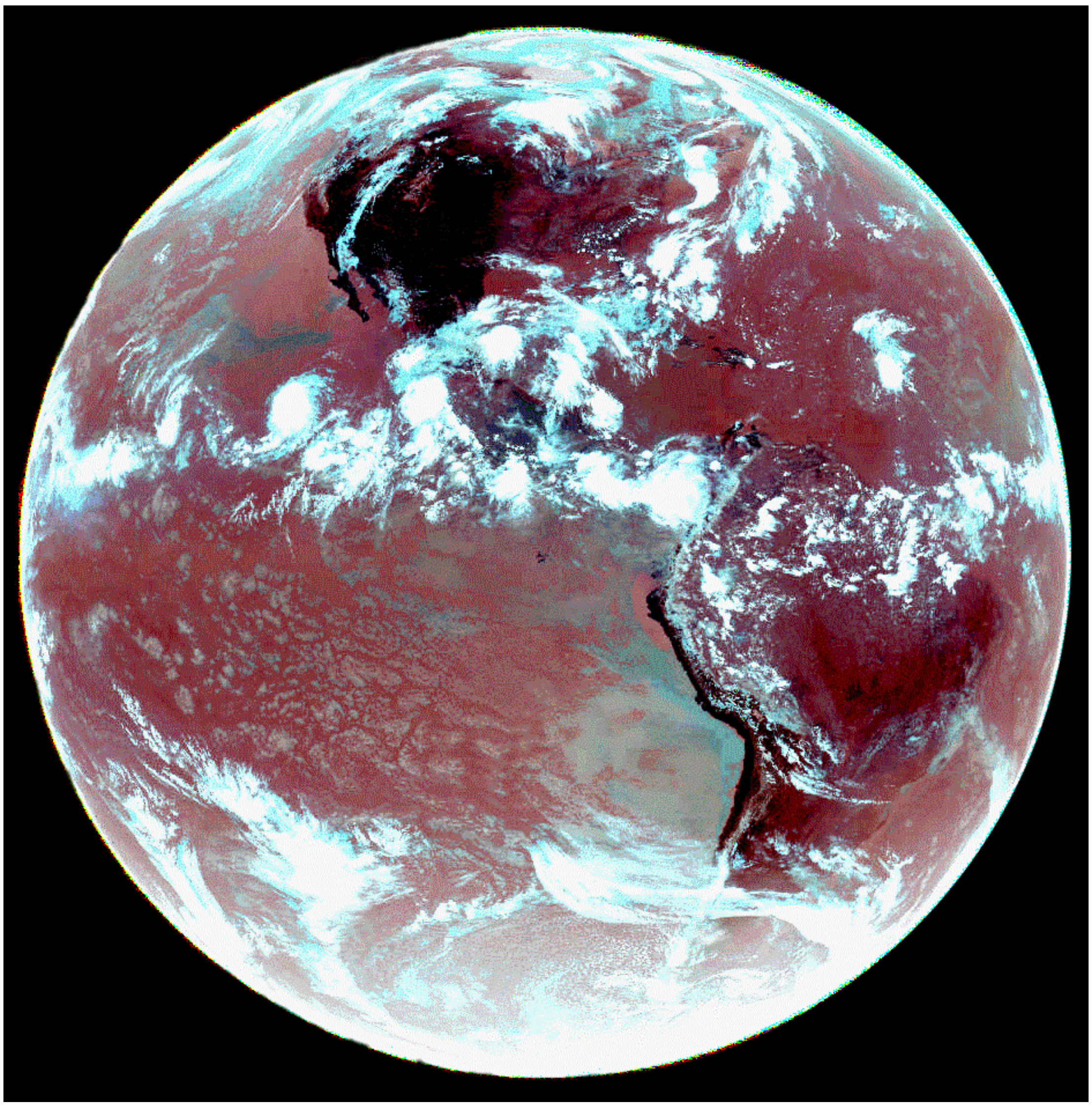

Figure 1-17. GOES infrared imagery. The different cloud colors tell you something about their height and water content.

b Landsat - IR San Diego - 7 May 1996 (bands 6, 5 and 7)

Reflective infrared and thermal infrared data from LANDSAT 5 (the same scene shown above in Figure 1-10) are shown encoded as an RGB triple in Figure 1-18. Note how the hot asphalt and city features are bright in the red (thermal), while the park (grass) areas are green (cool, and highly reflective in short-wave IR)

Figure 1-18. Landsat image - Infrared wavelengths. (Red: 11 micron, Green: 1.65 micron, Blue: 2.2 micron)

c DMSP - IR and Microwave

Thermal radiation extends beyond the traditional region defined by SWIR, MWIR, and LWIR. Indeed, the thermal emission from blackbodies extends out to microwave wavelengths.

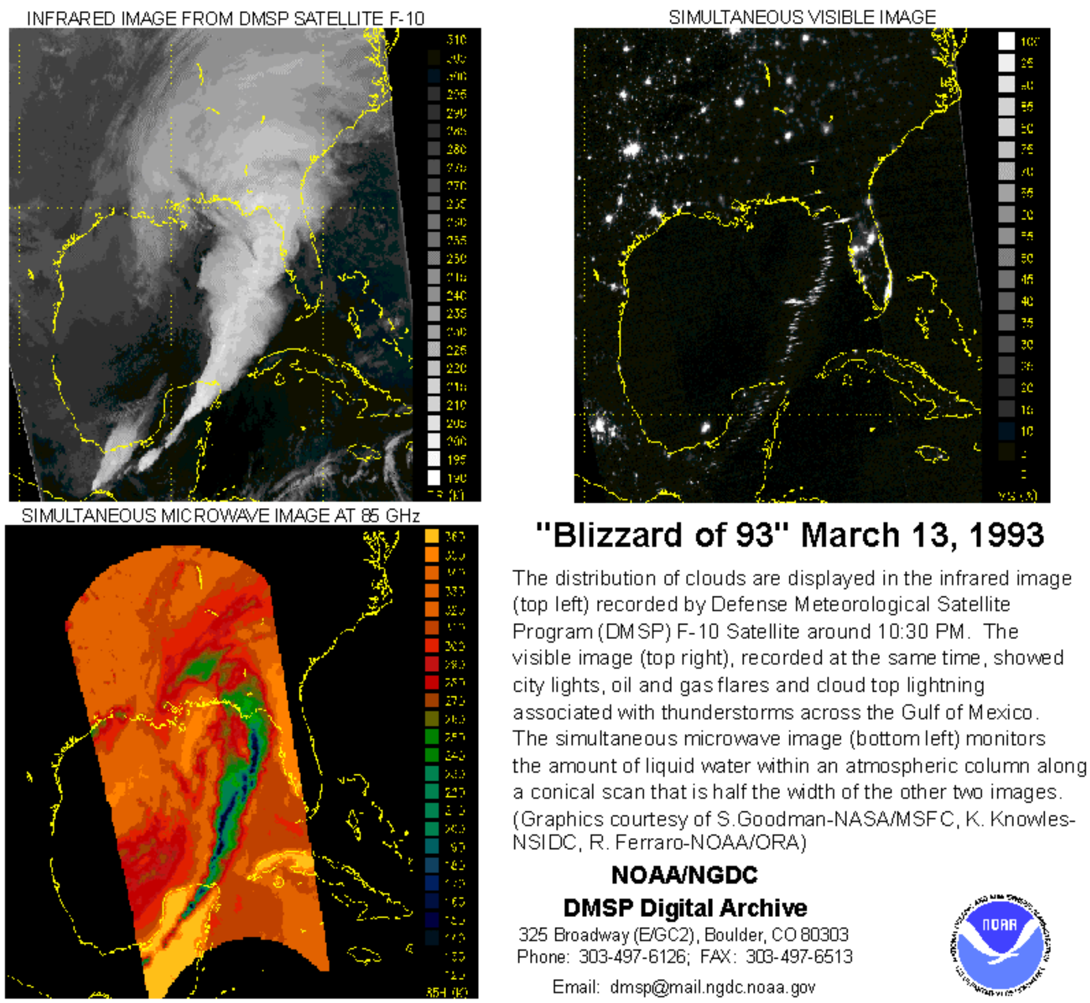

Figure 1-19 - DMSP: Visible, infrared, and microwave wavelengths. Microwave wavelengths are also emitted by 'thermal' or 'blackbody' radiators. Here, the 85 GHz band (0.3 cm) gives additional information on atmospheric water content.

3 Radar (SAR)

There are two civilian radar systems in current operation, the Canadian Radarsat, and the European ERS-2. NASA has flown the Shuttle Imaging Radar C mission twice (and now a third time as the Topographic Mapping Mission). The Japanese had a successful radar mission named JERS.

a RADARSAT - Maui - and the airport

Canada launched RADARSAT on November 4, 1995. The spacecraft is equipped with a C-Band (5.6cm), HH polarization, Synthetic Aperture Radar (SAR) capable of acquiring high-resolution (25m nominal - 8-100 m depending on the mode) imagery, with a swath width in the 50 - 500 km range.

a) b)

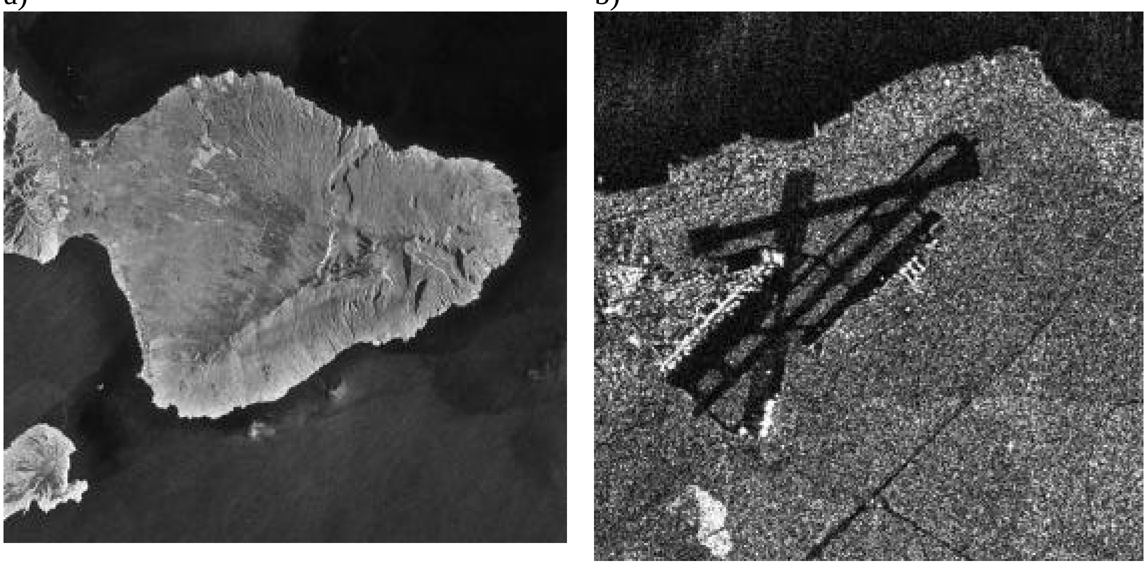

Figure 1-20. RADARSAT image of Maui, Hawaii

The SAR data 'look' substantially different at high resolution, which bothers some people. Note that the airfield on Maui is very dark, because the runway surfaces are very smooth compared to the wavelength of the radar - the radar energy bounces away from the satellite, and is not returned. Note the variations in grey level in the water in the left hand image. Differing wind-speeds on the surface cause variations in the scattering coefficient of the water.

b SIRC - Multi-wavelength/polarization

Maui

By comparison, the Shuttle Imaging Radar - C mission carried multi-wavelength, multi-polarization capabilities. A scene similar to the one above from RADARSAT is shown here, for Maui, Hawaii. Resolution is similar to that of RADARSAT.

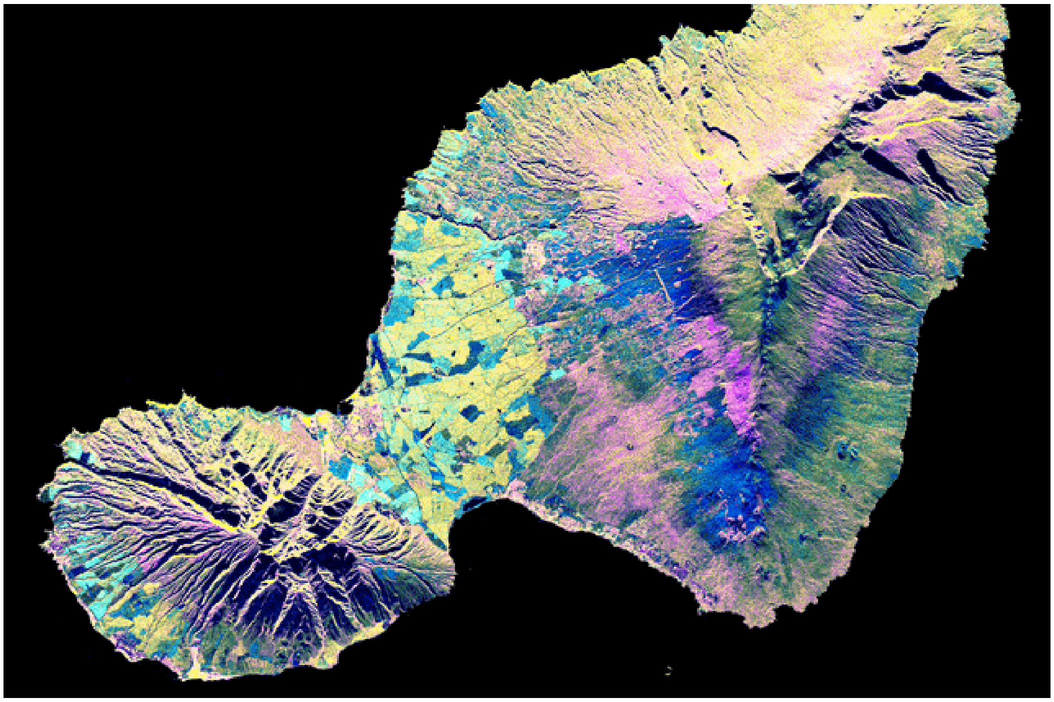

Figure 1-21. SIR-C image of Maui. This image was acquired by Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) onboard the space shuttle Endeavor on April 16, 1994. The image is 73.7 kilometers by 48.7 kilometers (45.7 miles by 30.2 miles) and is centered at 20.8 degrees North latitude, 156.4 degrees West longitude. North is toward the upper left. The colors are assigned to different radar frequencies and polarizations of the radar as follows:
red is L-band, horizontally transmitted and received;
green is C-band, horizontally transmitted and received; and
blue is the difference of the C-band and L-band channels.
http://www.jpl.nasa.gov/radar/sircxsar/maui.html)

Figure 1-20 shows the "Valley Island" of Maui, Hawaii. The cloud-penetrating capabilities of radar provide a rare view of many parts of the island, since the higher elevations are frequently shrouded in clouds. The light blue and yellow areas in the lowlands near the center are sugar cane fields. The three major population centers, Lahaina on the left at the western tip of island, Wailuku left of center, and Kihei in the lower center appear as small yellow, white or purple mottled areas.

West Maui volcano, in the lower left, is 1800 meters high (5900 feet) and is considered extinct. The entire eastern half of the island consists of East Maui volcano, which rises to an elevation of 3200 meters (10,500 feet) and features a spectacular crater called Haleakala at its summit. Haleakala Crater was produced by erosion during previous ice ages rather than by volcanic activity, although relatively recent small eruptions have produced the numerous volcanic cones and lava flows that can be seen on the floor of the crater. The most recent eruption took place near the coast at the southwestern end of East Maui volcano in the late 1700s. The multi-wavelength capability of the SIR-C radar also permits differences in the vegetation cover on the middle flanks of East Maui to be identified. Rain forests appear in yellow, while grassland is shown in dark green, pink and blue.

SIRC - San Diego Harbor

This radar image shows the city of San Diego, California and surrounding areas. San Diego Bay is in the bottom left of the image and is separated from Mission Bay by the Point Loma Peninsula. North Island, home of the U.S. Naval Air Station and Silver Strand are on the left side of San Diego Bay. This image was acquired on October 3, 1994 by the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) onboard the space shuttle Endeavour.

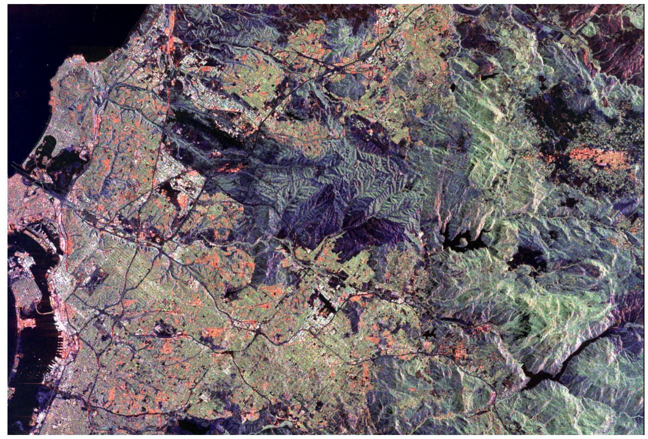

Figure 1-22a. Image P48773

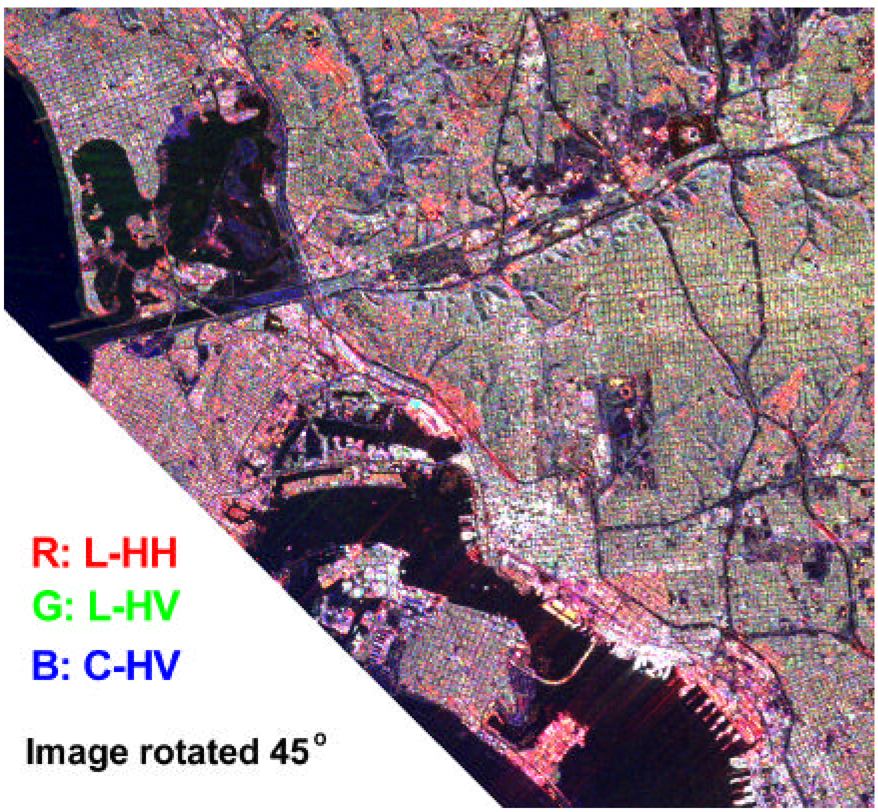

Figure 1-22b. San Diego image from the Shuttle Imaging Radar, L-band and C-band data. Subset of image P48773.

C Three Axes

One of the themes we will see as we progress is that there are three dimensions associated with remote sensing imagery - spatial, spectral, and temporal. These are in general somewhat mutually exclusive. One can have high spatial resolution, but only at low temporal coverage (like Landsat - decent pictures, but only once every 15 days or so). You can have high temporal coverage (like GOES, once every 30 minutes), but then your spatial resolution is only 1 kilometer. If you want spectral coverage (multi-spectral or hyperspectral), you will pay a penalty in the other dimensions.

Similarly, there is a conflict between resolution and field of view - image a larger area, and in general you will have lower spatial resolution.

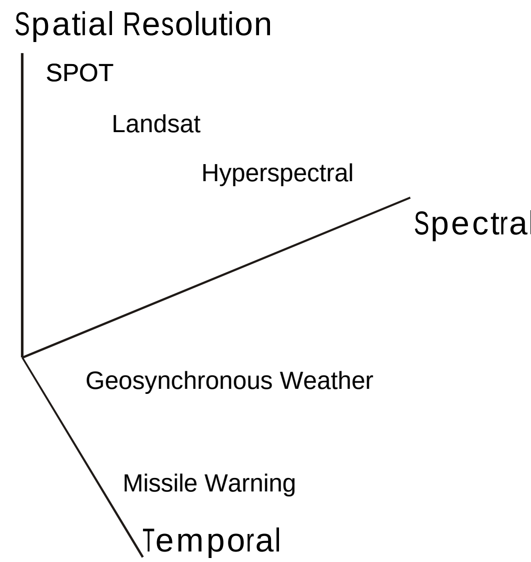

Figure 1.23

D Problems

1) List 10 elements of information that could be determined for NOB from imagery.

2) What wavelengths of EM radiation are utilized in the images shown in this chapter? (This is really a review question, best answered after completing chapter 2).

3) Construct a table/graph showing the relationship between ground resolution and area of coverage for the sensors shown in this chapter. (Also a review question, really.)

4) Compare the various images of San Diego Harbor. What are the differences in information content for the high-resolution panchromatic systems (SPOT, IRS-1C), the multispectral system (LANDSAT, visible and infrared), and the radar system. Which is best for lines of communication? Terrain categorization? Air order of battle? NOB?

